Exploitation status of infralittoral abalone (*Haliotis midae*) and alikreukel (*Turbo sarmaticus*) in the southern section of the Eastern Cape coast, South Africa

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Intertidal size–frequency distributions and densities for *Haliotis midae* and *Turbo sarmaticus* were examined at 10 sites experiencing varying pressure of human exploitation along the southern section of the Eastern Cape coast, South Africa. Target species' densities and maximum sizes were related both to the numbers of collectors on the shore and to indirect indicators of exploitation such as number of households in the vicinity and distance to the nearest beach access point. For both species, there was variation in density ($P < 0.05$) and size ($P < 0.05$) among sites, with densities ranging between 0.03–2.23 m^{-2} and 0.07–4.93 m^{-2} for *H. midae* and *T. sarmaticus*, respectively. Maximum sizes ranged between 49.4–153.5 mm (*H. midae*) and 28.3–104.4 mm (*T. sarmaticus*) shell length. Population parameters such as mean maximum size and total density were significantly negatively related to exploitation indicators for both species. In addition, densities of sexually mature and legal-size individuals of *T. sarmaticus* were significantly negatively related to the number of households. However, only for *H. midae* were densities of subadults significantly negatively related to the number of collectors, suggesting that reproduction of abalone may be suppressed at the most exploited sites. Exploitation of *T. sarmaticus* tends to be localized near population centres, whereas *H. midae* is collected over a larger range of sites. Overall, *T. sarmaticus* is less affected by exploitation than *H. midae*.

Introduction

In South Africa, marine resources have been exploited for subsistence purposes for approximately 100 000 years.[1] Over the past few decades, however, the intensity of exploitation has increased greatly as a result of both rapid human population growth and a concentration of people into coastal areas.[2,3] The Subsistence Fisheries Task Group, appointed by Marine and Coastal Management of the Department of Envronmental Affairs and Tourism, concluded that most true subsistence fisheries occur along the east and south coasts of the country, where the focus is primarily on intertidal and estuarine invertebrates.[4] To a large extent, however, our understanding of both exploitation patterns and their effects on resources are based on a few localized investigations (see references below), with large stretches of the coastline not yet studied.

Ecological effects of subsistence exploitation have been demonstrated in the former homeland of the Transkei, where indigenous coastal communities supplement their diets with marine resources.[2,5–8] In these studies, subsistence fishers were shown to have a dramatic impact on populations of the brown mussel (*Perna perna*) and limpets (such as *Scutellastra granularis* and *Cellana capensis*). It was shown that both the relative abundance and mean modal size of target organisms were significantly reduced in areas of high exploitation pressure[5,7,9] and, in extreme cases, overexploitation also reduced intertidal biodiversity.[10–12] In KwaZulu-Natal, a long-term study showed that overexploitation was affecting the abundance of organisms, including mussels (*P. perna*), rock lobsters (*Panulirus homarus*) and oysters (*Striostrea margaritacea*) and that stocks appeared to be diminishing rapidly.[13,14] In contrast, information on exploitation and standing stocks of target species between the Western Cape and Transkei are scarce.

In the southern section of the Eastern Cape, the giant periwinkle (*Turbo sarmaticus*) and the abalone (*Haliotis midae*) are amongst the most heavily exploited target organisms (S. Kaehler, unpubl data). *Haliotis midae* has a high economic value and is harvested commercially, poached for sale and collected for food, whereas *T. sarmaticus* is exploited primarily by the subsistence sector for food and to a lesser extent by the recreational sector for bait.[2,15,17] Both species occur in the intertidal and shallow subtidal zones. It is these easily accessible areas of the shore that are utilized primarily by subsistence fishermen. Few studies have been conducted on populations of either *H. midae* or *T. sarmaticus* in this area.[3,15,17] Work on *H. midae* in the Eastern Cape has focused primarily on subtidal stocks and indicated that high levels of fishing effort appear to have caused a decrease in emergent abalone populations (that is, abalone that have emerged from their cryptic juvenile habitat to more open, visible locations) and average size.[18,19] Similarly, *T. sarmaticus*, the preferred food item for many impoverished communities,[3] is heavily exploited, with large specimens becoming increasingly scarce outside marine reserves.[16]

The aims of the study reported here are 1) to investigate the effects of exploitation on the populations of two of the most heavily exploited infralittoral organisms along the south coast and 2) to determine whether aerial surveys of collector densities and other indirect predictors of exploitation (that is, density of adjacent households, distance to access points) can be used to predict exploitation hotspots.

Materials and methods

Biological surveys

Ten sites were selected within a 70-km stretch of coastline (Table 1, Fig. 1). Five of these sites — Old Woman's, Mpekweni, Begha, Hamburg East and Hamburg West — are located in the former Ciskei homeland (Fig. 1). All the sites are either rocky headlands or wave-cut platforms, consisting of quartzitic sandstone reefs extending perpendicularly from the shore out to sea, with boulders between the reef ridges and gullies. Sites were also chosen for their similar biological communities, which were characterized by the brown mussel, colonial polychaete (*Gunnarea capensis*), pink-lipped topshell (*Oxystele sinesis*) and pink encrusting coralline algae (*Lithothamnion, Corallina* sp., *Gelidium pristoides, Eklonia radiate* and *Ulva* spp.). In particular, sites were chosen for their abundance of the sea urchin (*Parechinus angulosus*). A strong positive relationship has been shown between *P. angulosus* and juvenile *H. midae,* where urchins play a role as nursery sites to juvenile abalone.[20,21]

Surveys were conducted at spring low tides between March and June 2003, in the infralittoral, which includes the lower intertidal zone and shallow subtidal zone, below the lower limit

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of the distribution of *Gunnarea capensis.* This is the area most vulnerable to subsistence exploitation. At each site, along two 30-m transects, sited parallel to the shore, 15 1-m^2 quadrats were sampled at random, excluding non-habitable areas such as sand patches. All *H. midae* and *T. sarmaticus* found within each quadrat (including in caves, crevices and under boulders) were scored and their shell lengths measured to the nearest 0.1 mm using Vernier callipers. Total densities were further sub-divided into densities of subadults, sexually mature animals and those of legal size. The minimum legal size (MLS) for collection is 63.5 mm shell width or 73.7 mm shell length for *T. sarmaticus*[17] and 114 mm shell width or 141 mm shell length for *H. midae.*[18] Sexual maturity was taken to be the size at which 50% of individuals were sexually mature, this being 50 mm and 53.7 mm shell length for *T. sarmaticus* and *H. midae,* respectively.[18,22,23] Subadults were defined as organisms with a shell length less than the size at 50% sexual maturity, i.e. 50% of the organisms that are not yet reproductively mature.

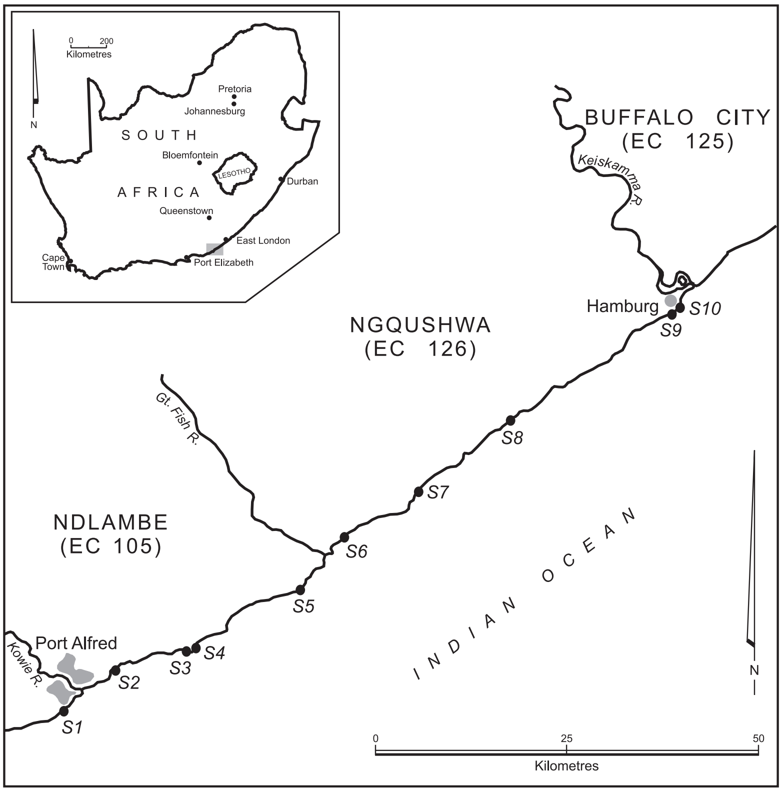

Fig. 1. Coastal region of the Eastern Cape, with the location of the ten study sites.

Exploitation estimates

To determine the density of collectors on the beach, six aerial surveys were conducted between Port Alfred and East London between 2002 and 2004. The number of collectors (identified as people on rocks collecting or carrying bags, as opposed to seaweed gatherers and fishermen), were scored and their average densities determined within a 1.5 km and 2.5 km linear distance, either side of each site and then standardized to people per km. These distances were chosen as previous surveys in the area showed that subsistence collectors on average did not walk more than 5 km along the shore to collect organisms. In the study area most stretches of rocky shore also tend not to exceed 5 km in length. However, because much of the illegal collection of marine resources occurs at night (when aerial surveys could not be conducted), two further, indirect exploitation 'predictors' were determined. The number of households within a 7-km radius of a site and distance to the nearest beach access point (that is, distance to the nearest footpath) were determined for each site from spatially referenced data provided by the Department of Surveys and Mapping (processed using ArcView 3.2; Environmental Systems Research Institute, Inc.).

Statistical analysis

ANOVAs were used to determine if density and maximum size of both species varied significantly among sites (using STATISTICA 6.0). Assumptions of heterogeneity and normality for ANOVA were not met, even after square-root transformations.[24] However, because group sizes were equal and large (n = 30), ANOVA is thought to be robust against such heterogeneity.[25] ANOVA and non-parametric Kruskal-Wallis analysis both gave similar results. Consequently, only the more powerful results for the ANOVA are presented here.

A Forward Stepwise Multiple Regression was performed between exploitation parameters (that is, density of collectors on the shore within a 1.5 km linear distance either side of each site, number of households within 7 km of the sites and distance to the nearest beach access point) and density and mean size of the largest 10% of the population of the two target species. Owing to non-linearity of relationships, multiple regressions were performed on log-transformed data.

Results

Densities of both species varied significantly between sites (*H. midae,* $F = 5.66$, $P < 0.001$, d.f. = 9, 290; *T. sarmaticus,* $F = 12.1$, $P < 0.001$, d.f. = 9, 290). A Newman-Keuls test further revealed that Riet River West had a significantly higher density of *H. midae* than all other sites, which tended to be homogeneous with each other with the exception of Hamburg East, which had significantly lower densities than Mpekweni and Old Woman's. *Turbo sarmaticus* did not exhibit as clear a pattern as *H. midae*: overall, Hamburg East and Hamburg West had the lowest densities and Riet River East and Rufanes the highest densities.

The maximum sizes of both species in each quadrat varied significantly between sites (*H. midae,* $F = 11.00$, $P < 0.001$, d.f. = 9, 290; *T. sarmaticus,* $F = 11.96$, $P < 0.001$, d.f. = 9, 290). A Newman-Keuls test further revealed that the maximum size of *H. midae* was significantly larger at Riet River West than at all other sites. There were significantly larger *T. sarmaticus* at Riet River East and significantly smaller individuals at Hamburg East and West (Table 1).

At Riet River West, *H. midae* occurred at the highest densities (2.23 ± 1.8 m^{-2}), and had the highest proportion of legal-size animals (2.9%) and the largest maximum shell length (153.5 mm), which is close to the maximum size for the region (Fig. 2; Table 1.). Populations with no legal-size animals and maximum sizes ranging between 49.4 and 107.6 mm tended to be situated in the former Ciskei and near Port Alfred (Fig. 2; Table 1.). The lowest densities and sizes were at Begha and Hamburg West, where no sexually mature animals were found (Fig. 2; Table 1). At Riet River East, *T. sarmaticus* occurred at the highest density (4.93 ± 4.90 m^{-2}), and had the highest proportion of legal-size animals (12%) and one of the largest maximum shell lengths (102.1 mm) (Fig. 3; Table 1.). Near the population centres of Hamburg and Port Alfred, densities were lower and sizes smaller, with no animals of reproductive size: the smallest maximum sizes (59.5 mm and 28.3 mm) were observed at

Table 1. Comparative data on exploitation predictors and population structures of *Haliotis midae* and *Turbo sarmaticus* for this study and other studies along the Eastern Cape coastline, South Africa.

					Haliotis midae			*Turbo sarmaticus*		
Site name	Site*	Number of collectors (km^{-1})	Distance to access point (km)	Number of households (7-km radius)	Maximum size (mm)	Mean density (m^{-2})	% Legal size	Maximum size (mm)	Mean density (m^{-2})	% Legal size
Kelly's Beach	S1	0.2	0.48	434	97.4	0.67 ± 0.9	0	67.2	1.5 ± 2.4	0
Rufanes	S2	0.45	1.03	213	93.3	0.77 ± 2.6	0	69.4	2.06 ± 2.84	0
Riet River West	S3	0.2	1.46	110	153.5	2.23 ± 1.8	2.9	85.9	1.13 ± 1.4	10
Riet River East	S4	0.2	1.15	127	115.1	1.03 ± 1.9	0	102.1	4.93 ± 4.9	12
Great Fish Point	S5	0.45	3.3	224.5	124.1	0.67 ± 1.9	0	104.4	0.9 ± 1.4	7.5
Old Woman's	S6	0.27	0.45	167.5	102.2	1.27 ± 1.6	0	79.4	2.37 ± 2.3	7
Mpekweni	S7	0.23	0.79	106.5	107.6	0.7 ± 0.9	0	87	2.2 ± 3.7	9
Begha	S8	0.15	0.86	162.5	59.3	0.67 ± 1.1	0	74.4	1.9 ± 1.9	1.75
Hamburg West	S9	0.75	0.3	359.5	49.4	0.03 ± 0.2	0	28.3	0.067 ± 0.3	0
Hamburg East	S10	1.38	0.71	388	90.5	0.3 ± 0.8	0	59.5	0.7 ± 1.4	0
Kelly's Beach[a]								60–69	0.27	0
Bird Island[a]								110–120	1.5	32.2
Great Fish Point[b]					110	1.50	0			

[a]Foster and Hodgson[3]; [b]Wood.[18]
*See Fig. 1 for locations.

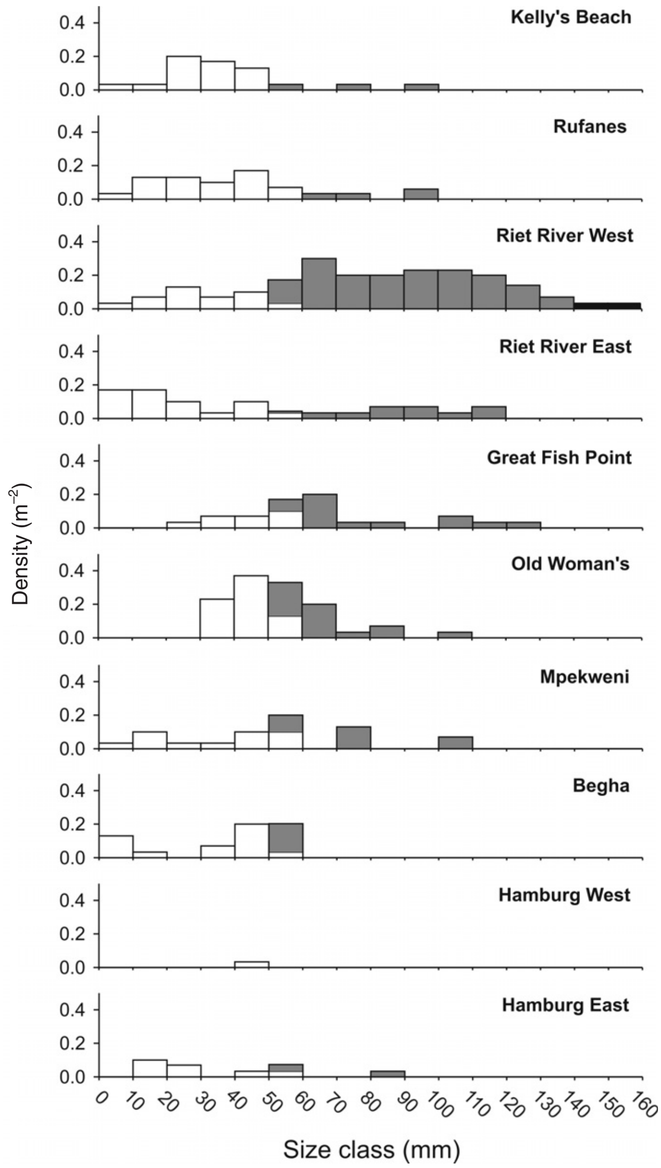

Fig. 2. Size density distributions (shell length in mm) of *Haliotis midae* in the infralittoral region for ten sites surveyed along the Eastern Cape coastline (□ = <53.7 mm, subadult; ■ = >53.7 mm, adult; ■ = >141 mm, legal size).

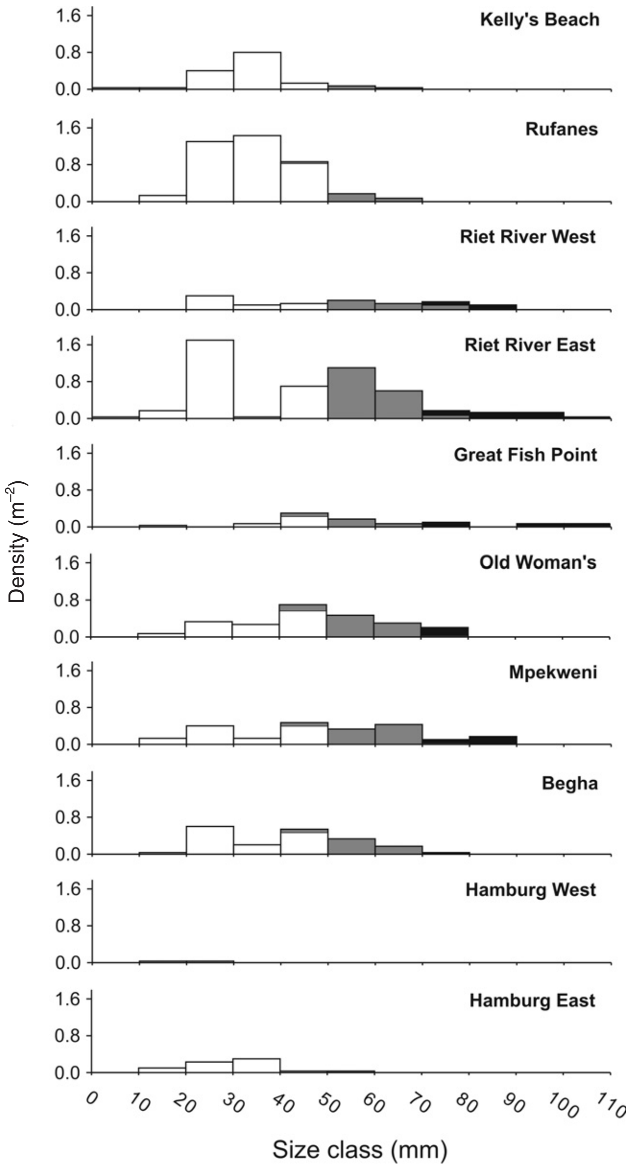

Fig. 3. Size density distributions (shell length in mm) of *Turbo sarmaticus* in the infralittoral region for ten sites surveyed along the Eastern Cape coastline. (□ = <50 mm, subadult; ■ = >50 mm, adult; ■ = >73.7 mm, legal size).

Hamburg East and West, respectively (Fig. 3; Table 1).

The number of collectors within a 1.5 km distance either side of each site ranged from 0.2 (Kelly's Beach) to 1.38 km^{-1}(Hamburg East) (Table 1). The highest densities of collectors were found in areas near to large coastal settlements such as Hamburg (0.75–1.38 km^{-1}) and the low densities were recorded near relatively secluded parts such as Riet River Point (0.2 and 0.45 km^{-1}). The distance to the nearest beach access point ranged between 0.3 km near large coastal settlements (Hamburg West) and 3.3 km at relatively remote locales (Great Fish Point), with the number of households within a 7-km radius ranging from 359–434 near large coastal settlements or population centres to 107–127 at more secluded areas or expensive holiday or retirement centres (Table 1).

There was a negative relationship between overall density of invertebrates and the number of collectors on the shore for both species (Table 2; Fig. 4a). Mean size (shell length) of the largest 10% of the population and the distance to the nearest access point for both species displayed a positive significant relationship, with *T. sarmaticus* also having a negative relationship between the mean size of the largest 10% of the population and the number of collectors on the shore (Table 2; Fig. 4b,c). Subadult *H. midae* densities were negatively correlated with the number of collectors on the shore (Table 2; Fig. 4d). The number of households within a 7-km radius was negatively related to the density of sexually mature *T. sarmaticus* of legal size (Table 2; Fig. 4e,f).

Table 2. Multiple regression analysis[30] of potential exploitation indicators [i.e. number of collectors (km^{-1}), number of households (7-km radius), distance to access point (km)] on population parameters (i.e. total density, density of subadults, density of sexually mature individuals, density of individuals of legal size, mean size of largest 10%) of *Turbo sarmaticus* and *Haliotis midae.*

Turbo sarmaticus	*B*	s.d.	*P*-value*
Total density (R^2 = 0.47; P = 0.029, d.f. 3)			
Intercept	0.62	0.09	0.002
Collector density	–1.22	0.46	0.029
Largest 10% (R^2 = 0.76; P = 0.007, d.f. 2)			
Intercept	1.76	0.09	< 0.001
Collector density	–0.75	0.28	0.031
Distance to access point	0.54	0.21	0.039
Sexually mature individuals (R^2 = 0.63; P = 0.006, d.f. 1)			
Intercept	1.33	0.32	0.003
Number of households	–0.50	0.14	0.006
Individuals of legal size (R^2 = 0.44; P = 0.035, d.f. 1)			
Intercept	0.46	0.16	0.022
Number of households	–0.18	0.07	0.035
Haliotis midae			
Total density (R^2 = 0.61; P = 0.008, d.f. 1)			
Intercept	0.41	0.05	0.001
Collector density	–0.92	0.26	0.008
Largest 10% (R^2 = 0.43; P < 0.041, d.f. 1)			
Intercept	1.79	0.07	<0.001
Distance to access point	0.59	0.24	0.041
Subadult individuals (R^2 = 0.6; P = 0.04, d.f. 3)			
Intercept	0.08	0.08	0.365
Collector density	–0.58	0.18	0.016

*Only statistically significant relationships (at the 95% confidence level) are presented.

Discussion

For both *H. midae* and *T. sarmaticus*, population characteristics varied significantly between sites. Overall, densities were lowest and sizes smallest near the population centres of Port Alfred and Hamburg (namely, Kelly's Beach, Rufanes, Begha and Hamburg East and West), whereas higher densities and larger sizes were found at more remote locations. Because all study sites were chosen for their similar physical nature and biological communities, it is likely that human exploitation pressure was at least partly responsible for the observed differences in population structure among sites.

Many intertidal taxa have decreased considerably in numbers and even disappeared in some locations due to over-exploitation.[26] In the former Transkei, for example, populations of *Perna perna* and the limpet *Cymbula oculus* have been shown to be highly susceptible to stock depletion as a result of traditional gathering.[7] *Cymbula oculus* displayed smaller adult sizes, lower densities, smaller biomasses and lower survivorship at harvested sites compared with populations in marine protected areas.[27] Marked differences in abundance, modal size and mean size of *P. perna* were demonstrated between exploited and unexploited sites,[5,28,29] while for the limpet *Helcion concolor* a reduction in maximum size could be directly related to excessive collection.[30]

In the current study, the demographic status of both target species was poorest in the vicinity of coastal settlements, with few or no sexually mature animals within 7 km of major population centres (Hamburg East and West, Kelly's Beach and Rufanes River), suggesting that the two species were over-exploited at these sites. As expected, the number of collectors on the shore was highest in the vicinity of Hamburg and Port Alfred. The density of households was significantly and positively correlated with collector densities (see also ref. 6). Distance to the nearest beach access point tended to be greatest in remote areas between the two major settlements.

Total densities of both *T. sarmaticus* and *H. midae* were significantly negatively related to the number of collectors on the shore. The lowest densities were observed in the vicinity of Hamburg, where collector density was highest, whereas the highest densities were observed near the relatively inaccessible Riet River Point, where collector densities were an order of magnitude lower. For *T. sarmaticus*, total densities close to population centres were similar to those previously recorded from exploited sites (0.4–0.68 individuals per m^2), while less accessible sites typically exhibited higher densities than those reported from unexploited shores in previous studies (1.27–2.85 individuals per m^2).[3,15] This suggests that while *T. sarmaticus* was over-exploited close to population centres, relatively unexploited refuge populations persist in more remote areas. Similar tendencies of reduced size and densities in response to human exploitation have previously been described for *T. sarmaticus.*[2,3,15,31] While no comparative studies are available for infralittoral populations of *H. midae*, exploitation has been shown to reduce subtidal densities.[2,26]

For both species, the average size of the largest 10% of organisms was significantly and positively related to the distance from the nearest beach access point. Similar relationships between accessibility and exploitation pressure and effects have previously been demonstrated in Chile and California.[32,33] For *T. sarmaticus*, the mean size of the largest 10% of organisms was, furthermore,

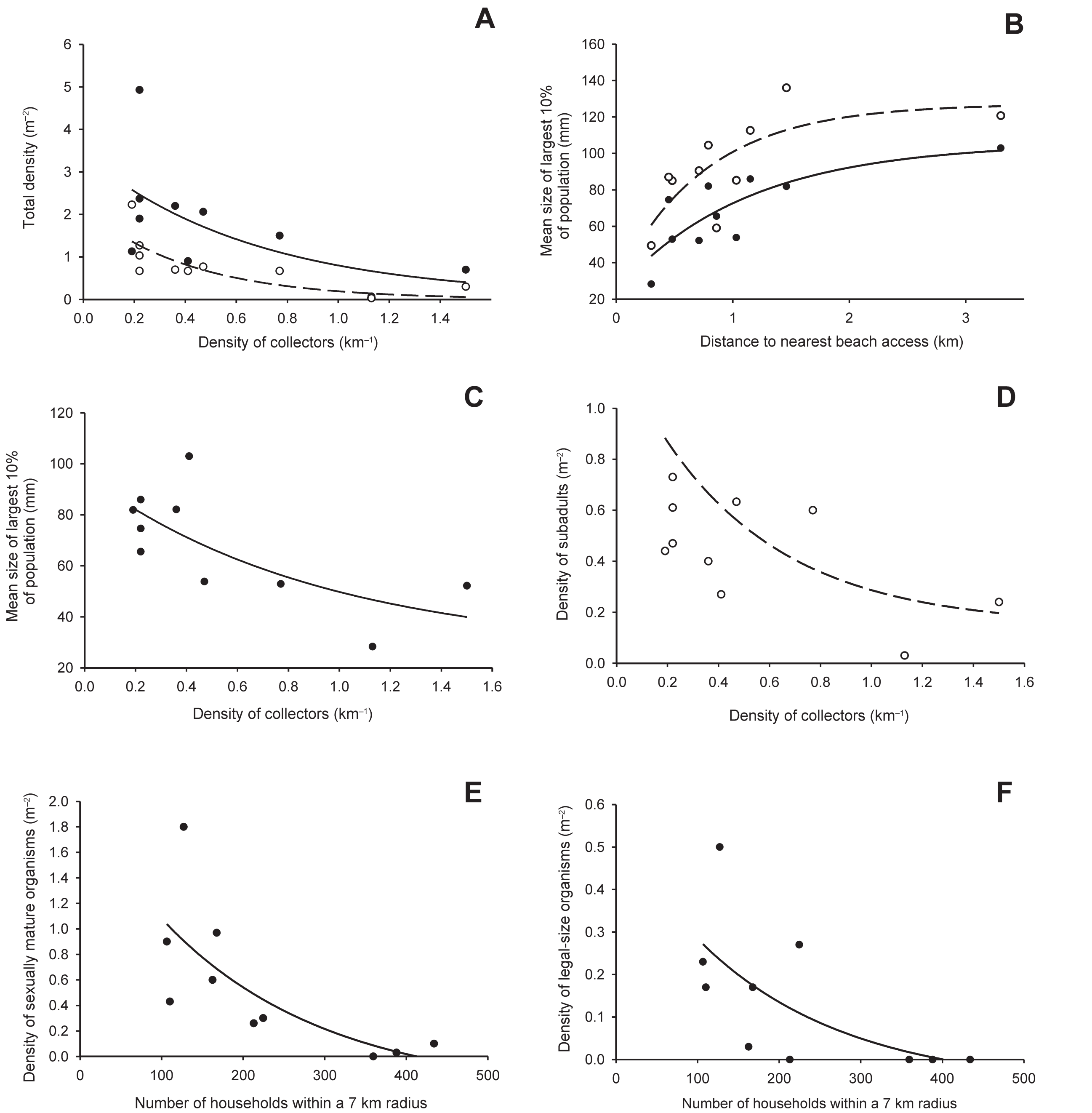

Fig. 4. Significant regressions for (**A**) total density and the number of collectors; (**B**) the mean size of the largest 10% of the population and the distance to the nearest access point; (**C**) the mean size of the largest 10% of the population and the density of collectors; (**D**) the density of sub-adults and the density of collectors; (**E**) the density of sexually mature organisms and the number of households and (**F**) the density of legal-size organisms and the number of households, for both *Turbo sarmaticus* (●, ——) and *Haliotis midae* (**O**, – –).

negatively related to the number of collectors on the shore.

The two target species exhibited very different responses to exploitation pressure on individual size classes. For *T. sarmaticus,* both the densities of sexually mature and legal-size organisms were negatively related to the number of households within 7 km of the study sites. This was not surprising, because *T. sarmaticus* has no commercial value and is typically harvested by subsistence fishers within a radius of 7 km from their homes (S. Kaehler, unpubl. data). As larger organisms provide a better return in terms of food, harvesting tends to be size selective, as observed in Transkei, where 50% of the animals taken are over 60 mm shell length, and therefore larger organisms will be more affected by exploitation than the juveniles.[7] In contrast to adults, the density of subadult organisms was not significantly related to any of the exploitation predictors (although sites with many collectors tended to have fewer subadults). This suggests that while infralittoral sites close to coastal settlements may be overexploited and retain only a few reproductively active individuals, juveniles will still recruit into the populations either from refuge sites or from subtidal stocks (see also refs 7, 34).

Haliotis midae exhibited very different density patterns. No significant relationships were found between any of the exploitation predictors and the density of sexually mature organisms or those of legal size. This was primarily due to the overall low densities of large abalone at all but one site. While the scarcity of infralittoral *H. midae* may in part be because larger abalone tend to aggregate in deeper waters,[18] the presence of legal-size and/or larger numbers of reproductive organisms at the least accessible intertidal sites suggests that their exploitation may be far more intense and widespread than collection of *T. sarmaticus.* This is seen from the middens of poached shells, where most shells are under the legal size limit (Fig. 5). Furthermore, because of the high commercial value of abalone, illegal harvesting has spread into remote and secluded locales.[35] Where previously only local abalone was harvested, it is now financially worthwhile to hire transport, equipment and even professional divers to exploit ever less accessible sites. While many professional poachers harvest subtidally, the removal of adult animals is likely to reflect the abundance of juveniles higher up the infralittoral. Furthermore, with larger individuals becoming increasingly scarce, many smaller and illegally sized individuals are now being harvested (Fig. 5).[34,35]

We observed a significant negative relationship between the number of collectors and the density of subadult *H. midae.* Young abalone were scarce at the most exploited sites, especially in the vicinity of Hamburg. This is one of the few coastal settlements that has periodically granted some collectors special permits that exempt them from the national recreational ban on the collection of abalone, to promote a small-scale fishery. Both infralittoral and subtidal populations of *H. midae* have been heavily exploited in this area for several years. As the harvesting of large numbers of small individuals is unlikely to be as profitable, the observed scarcity of juvenile abalone in the vicinity of Hamburg suggests that the over-exploitation of sexually mature organisms, both intertidally and subtidally may have reached a point where local reproductive output is diminished and stocks may be failing to recover (see also ref. 26).

In the current study, both *T. sarmaticus* and *H. midae* were observed to be heavily over-exploited. For *T. sarmaticus*, however, six out of ten study sites most likely acted as reproductive refuge sites, as they still supported large, legal-size individuals. It is unlikely that remote populations of *T. sarmaticus* will be more heavily exploited in the near future, because this species is harvested only on a local scale by subsistence collectors that are concentrated in a small number of widely dispersed coastal settlements. In contrast, *H. midae* was far more adversely affected by exploitation. With the exception of Riet River West, sexually mature individuals were scarce at most sites and even the abundance of subadults was reduced in areas of high exploitation pressure. Additional evidence also suggests that the condition of abalone populations is deteriorating. At the remote Great Fish Point, for example, infralittoral abalone densities have decreased by almost 60% since sampling was first conducted,[18] and since the current survey, a further estimated 6000 individuals were removed during a single poaching event in 2004 (L. Proudfoot, unpubl. data). With few exceptions, even the most remote locations are now being targeted for the collection of *H. midae* and the sizes of harvested individuals are steadily decreasing. Because the poaching of abalone is not restricted to the infralittoral, it is likely that even remote and subtidal refuge populations will soon be over-fished. In view of the evident reduction in reproductive output and limited dispersal capabilities of haliotid larvae,[36,37] stocks of *H. midae* may soon reach a point where sustainability and recovery are unlikely.

More than 57% of variability in population structure overall between sites could be explained by the density of collectors and indirect estimates of exploitation pressure. Much of the residual variation is likely to have been due to natural environmental variation in wave exposure, coastal hydrography and/or productivity.[3,38] It should be possible to refine the survey method, however. In this and other studies, it was noticed that most subsistence collection occurred in relatively poor rural areas where a large proportion of collectors were unemployed and the average income was low. In contrast, coastal areas inhabited by

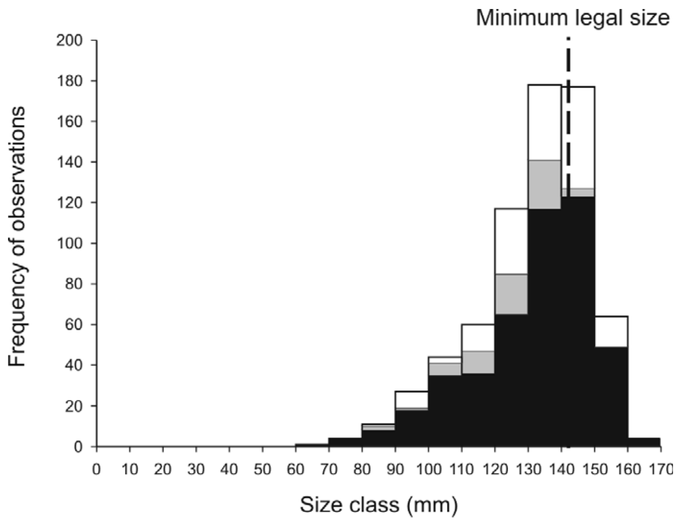

Fig. 5. Size range of harvested *Haliotis midae* seen from middens of poached shells from 'non-divers' at Great Fish Point = ■, Mpekweni = ▒ and Rufanes = □.

relatively wealthy holiday or retirement home owners, tended to retain healthier stocks, as local interest groups were generally able to prevent large-scale poaching. Data on population densities, income and level of unemployment are now all available in the form of census data. In future, these parameters may prove to be useful tools for locating potential exploitation hotspots and to facilitate taking remedial action.

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